ORIGINAL ARTICLE

Predictive Model for Heat Stress-related Symptoms Among Steel Mill Workers in East Java, Indonesia

Imam Munajat Nurhartonosuro[1], Shamsul Bahri Md Tamrin[1], Dayana Hazwani Mohd Suadi Nata[2], Karmegam Karuppiah[1], Ng Yee Guan[1], Gede Pramudya Ananta[3]

[1] Department of Environmental and Occupational Health, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia.
[2] Center for Toxicology and Health Risk Studies,, Faculty of Health Sciences, Universiti Kebangsaan Malaysia, Jalan Raja Muda Abdul Aziz, 50300 Kuala Lumpur, Malaysia
[3] Department of Software Engineering, Faculty of Computer Sciences and Information Technology, Universiti Tun Hussein Onn Malaysia, 86400 Johor, Malaysia

ABSTRACT

Introduction: As a tropical country, Indonesia's climate is hot and humid throughout the year, implicating hot workplace environment and leading to workers' susceptibility to heat stress exposure. Workers at a steel processing mills exposed to an extremely hot environment are prone to experience heat stress-related symptoms caused by occupational heat stress. **Methods:** The study aimed to build a predictive model of heat stress-related symptoms in steel mill workers based on physiological and environmental parameters. The respondents of this study were 119 operators exposed to a hot workplace in Surabaya, Sidoarjo, and Gresik, East Java, Indonesia. **Results:** The result as a high correlation ($p<0.05$) in predictive between the model Wet Bulb Globe Temperature (WBGT), core body temperature, heart rate and heat stress-related symptoms with R-value of 0.78 or 78%. In addition, there is a weak correlation between heat stress symptoms and systolic and diastolic blood pressure, as well as humidity factors and heat stress-related symptoms. Heat stress-related symptoms have a linear correlation with the value of WBGT, body core temperature and heart rate, while body core temperature has the highest value of correlation and WBGT is attributed to the lowest of all to the heat stress-related symptoms. **Conclusion:** With these values in hand, ones can predict whether workers will be exposed to heat stress work environment. Furthermore, with this model, it can predict heat stress-related symptoms in a particular workplace.

Keywords: Predictive model; Heat stress-related symptoms; Steel mills; East Java

Corresponding Author:
Shamsul Bahri Md Tamrin, PhD
Email: shamsul_bahri@upm.edu.my
Tel: +60173134792

INTRODUCTION

Tropical regions are located within the longitudinal line near the equator, between south and north latitude 23.5°, characterized by humid and hot climate throughout the year. The region is characterized by high ambient temperature and humidity that might pose greater risks of heat-related occupational health to the population (1), as compared to those working in subtropical areas. Studies have proven that an increase in humidity with temperature, in which the temperature depends on pressure, can exasperate heat stress in summer season in tropical regions (2). Moreover, a hot environment and high humidity could result in serious problem due to failure to reduce skin temperature via evaporation of sweat from the skin surface (3).

In addition, hot workplace environments, associated with very high temperatures, ranging from agricultural sectors (4), outdoor construction, road paving, forestry, maintenance of power line, traffic regulation, firefighting, and mining, or smelting or hot workplace environment with value of WBGT > 22°C and WBGT > 25°C performing very intense work increases the likelihood of the workers to experience heat strain at workplace (5). Factors that contribute to heat stress are classified into two aspects, i.e., environmental, and non-environmental factors. Environmental factors encompass air temperature and velocity, radiant temperature, and relative humidity, while non-environmental factors are personal factors (health condition, acclimatization, hydration, and clothing) and work factors (metabolic heat and workload) (6). There are numerous studies investigating factors that affect heat stress, such as temperature and air humidity (7), solar radiation effect on thermal sensation (8), air humidity effect on human heat stress in hot environment (3), and many others.

Steel mills are among industries that are exposed to extremely hot environment in their iron or steel processing where workers laboring, such an environment are susceptible to heat stress (9). Moreover, when the environmental setting is situated in a tropical area, the risk of occupational heat stress is more likely to present. Works related to labor at steel mill industries in the tropical workplace are susceptible to elevated ambient temperature and exposure to thermal stress environment. Such an environment might pose thermal hazard and heat-related illnesses to the workers, leading to reduce their productivity (1).

There are several studies investigating steel mill workers to heat stress exposure in different countries with varied environmental settings. Krishnamurthy et al. (1) conducted a study of steel mill workers in Southern India with tropical environmental condition. Based on their findings, for the moderate and heavy workload, most of the WBGT measurements (90%) were higher than the recommendation of threshold limit values (27.2^{o}C) found in blooming-mill/coke-oven. A study conducted by Fahed et al. (10) used the method of Wet Bulb Globe Temperature (WBGT) and Population Stability Index (PSI) to measure heat stress on the workers laboring at steel mills in Turkey. They revealed that about 86% of the workers complained about thermal discomfort in the mills. Likewise, a study conducted by Fahed et al. (10) investigated heat load on workers' health and activities in steel and iron mills located in Kardemir Steel Factory in Karabьk-Turkey using several indices, such as WBGT, PSI and HSI. They found that the highest WBGT values were associated with the unit of blast furnace area and continuous casting. Meanwhile, the rolling mills were recorded to have the highest Heat Stress Index (HSI) value. Venugopal et al. (11) studied steel factory in which they incorporated eight different industrial sectors in Southern India and revealed that workers in the steel mill industry were exposed to higher WBGT and had 9% prevalence of the workers had kidney stones among them.

In such a workplace, heat sources resulting from air temperature, wind, and high humidity, solar radiation, machinery operation, and muscular work process might lead to heat stress for workers. The most common symptom caused by heat stress can range from increased core body temperature, excessive sweating and thirst, kidney stone, muscular discomfort, insomnia, and decreased amount of urine (10). In addition, heat stress may lead to thermal-caused symptoms, such as heat rash, heat cramps, syncope, exertional rhabdomyolysis and heat stroke (12). Zheng et al. (13) clarified that the impact on risk of heat exposure can develop to become heat stress illness. The heat-related illness listed in industries as defined in a technical manual of the US Occupational Safety and Health Administration 1999 (14) is heat exhaustion, heat cramps, heat rashes, heat fatigue, heat collapse and heat stroke. In addition, several common symptoms of heat stress include, muscular discomfort, decreased amount of urine which might lead to acute kidney injury, heat rash, heat syncope, exertional rhabdomyolysis, sleep disruption, and excessive sweating (12 - 15). (15), (16)(17).

Chan et al. (18) conducted a study to develop a predictive model of heat stress among construction workers in Hongkong based on the WBGT index. Based on their study, they revealed that age, drinking habit, and work duration are the primary three significant predictors to determine the physiological responses of the construction workers. Another study investigating the development of a predictive model in heat stress was carried out by Lazaro & Momayez (19). In their study, Predictive Heat Strain (PHS) model was modified based on eight physical parameters, such as relative humidity, air temperature and velocity, radiation, metabolic rate, acclimatization, clothing factor, and posture, to predict more accurate core body and skin temperatures. They found that the modified PHS model was able to predict more accurate core body temperature more than the original PHS model.

Numerous studies investigated the correlation between environmental factors, such as air temperature, air velocity, relative humidity, and solar radiation, with the metabolic workload, clothing factor, and acclimatization factor with the occurrence of heat stress among workers. Seo et al. (20) investigated the effects of different combinations of relative humidity and ambient temperatures on the effective temperature of a wet bulb globe, in relation with two different types of clothing adjustment factors and their impacts on the heat strain level. In their study, the metabolic heat production was fixed at 350 watts while clothing factors were set with four different conditions. Rectal and skin temperature, perceptual and physiological heat strain, as well as body heat content, were determined. They revealed that rectal temperature and heat strain indices increased simultaneously in the four conditions. It is likely ACGIH's TLV limit of 38.0oC is surpassed when the core temperature increased continuously during the extended period of work under all condition. Previously, Zamani et al. (21) conducted a study assessing environmental factors, such as heat exchange conditions (stress) with the physiological response (strain) through cross-sectional study on 387 male farmers in West Azerbaijan, Iran in 2016. The study aimed to determine the association of heat indices, i.e., PSI, HSI, Humidex, and TSI with several physiological changes, such as blood pressure, heartbeat, and skin temperature. They found a direct association between heat indices and physiological parameters, excluding systolic blood pressure. Meanwhile, they revealed inverse associations between blood pressure, skin and core body temperature, and heartbeat with all heat indices.

Furthermore, numerous previous studies have established predictive models for physiological responses, thermal comfort, etc., in relation with heat stress in occupational workplace. For instance, Hajizadeh et al. (22) on ISO 7243 and ISO 9886 for the hot and dry environment, Błazejczyk et al. (23) on Universal Thermal Climate Index (UTCI) , Zare et al. (24) on heat stress indices (UTCI, WBGT, WBDT, TSI) in relation with physiological parameters, Vatani et al. (25) on UTCI for occupational heat stress assessment, Ioannou et al. (26) on ISO 7933:2018 using software for predicting heat strain, Lazaro & Momayez (19) on modified Predicted Heat Strain for the hot work environment, Yousif et al. (27) on the application of Thom's Thermal Discomfort Index, etc. Based on previous studies, there are over 100 predictive models of heat stress (28) are established for different settings of the workplace, regardless of no universal predictive model for various environmental workplaces, among others heat stress index (HSI), discomfort index, WBGT index, PHS, TWL, ISO 7933, TSI (tropical stress index), PhSI, environmental stress index, and others. However, there still a lack of studies that investigate the correlation between environmental factors, clothing factors, and metabolic workload with heat stress-related symptoms the workers might experience because of heat strain. Therefore, this study aimed to establish the correlation between several factors with workers' heat stress-related symptoms and to develop a predictive model of heat stress related symptoms for the workers at steel processing mills workplace in tropical environment.

MATERIALS AND METHODS

The study was a cross-sectional study that investigated individual risk factors, acute health score symptoms, environmental-related heat stress factors (WBGTin, relative humidity, clothing, and metabolic workload), physiological changes (body core temperature, heart rate, and blood pressure) to predict heat stress-related symptoms that workers exposed to heat environment might experience in this steel mills involved in this study, including iron making plant, steel making plant, and rolling mill with the operating temperature about 1800^{o}C. Observation and data collection were carried out in three different steel mills, steel mill A, steel mill B, and steel mill C, located in different cities, i.e., Surabaya, Sidoarjo, and Gresik in East Java. The targeted respondents involved in this study were 119 operators working indoor with exposure to extreme temperature, i.e., WBGT indoor >29.5^{o}C selected in this study based on the sample inclusion criteria, such as male workers, aged 18 – 55, employed not less than 3 months, and able to speak Indonesian. The number of samples was determined using Slovin's technique from the 170 targeted populations. We set the sampling error at 5% or the degree of confidence interval at 95%. The exclusion criteria in this study were those who had a history of medical problems such as diabetes, hypertension and heart disease that were verified by medical doctor. The companies were selected randomly based on the exposure to high temperature. The WBGT value was obtained from the indoor measurement in which workers were exposed to heat source at workplace using WBGT (Model Questemp, brand 3M, USA). The mean value of WBGT is calculated as follows (29):

$$WBGT_{ave} = \frac{WBGT_1 + (2 \times WBGT_2) + WBGT_3}{4}$$

Where $WBGT_{ave}$ is the average value of WBGT, $WBGT_1$ refers to 1.5 m height measurement, $WBGT_2$ refers to 1 m height measurement, and $WBGT_3$ refers to 0.5 m height measurement.

The data collection was conducted via walkthrough inspection, environmental monitoring, and personal assessment. Type or pattern of workers' workload was recorded using video recording for at least a 10-minute duration. The body core temperature was determined using infrared Thermometer GP100 (Bestone, China) directed toward forehead and blood pressure was measured using T 500 Plus Automatic Blood Pressure Monitor (Iwo Smartwatch, China) and recorded on the worksheet. The measurement was conducted three times and the results were averaged. Simultaneously, questionnaires that refer to the study conducted by Hazwani et al. (4) were distributed via purposive sampling technique and interviews were conducted to the workers. Prior to use, the questionnaire contents were validated by the expert panel consisting of board of supervisory committee, whose expertise in occupational health and safety and through pilot study. The draft of the questionnaire was discussed with a group of subject matter experts to review and evaluate the content of a questionnaire to ensure its relevance, accuracy, and appropriateness for the intended population. Besides, the draft of the questionnaire was also emailed to some experts to get a review and comment to ensure the validity of the content of the questionnaire. Body mass index (BMI) was measured according to WHO guideline chart (30) and a graph proposed by ACGIH (31) was used as guideline in heat stress assessment (32). Meanwhile, the occurrence of heat stress-related symptoms were measured based on scoring Acute Heat Symptoms Score (AHSS) based on American College of Sport Medicine WBGT index risk chart (33). All the data were processed and analyzed using univariate, bivariate and multivariate analysis with software SPSS version 25 and the output was generated in the form of regression equation as heat stress-related symptoms prediction model. The outcome should show a significance level of 0.05 for a two-sided test, and the test statistic must be greater than or equal to the critical value 1.96. Before conducting data collection, ethic clearance with identity of Ref.: UPM/TNCPI/RMC/JKEUPM/1.4.18.2 (JKEUPM), dated 28 November 2020 was obtained from Research Management Centre (RMC) Universiti Putra Malaysia, UPM.

RESULTS

Based on the study results from the total 119 respondents, the highest occurrence of symptoms the workers (54.62%) in the three mills experienced were severe thirst and excessive sweating due to hot environment (Table I). These symptoms are related to each other since excessive sweating will result in severe dehydration, leading to a worker's deficiency of body liquid. Thus, it will affect in a feeling of severe thirst, indicating of hydrating or liquid intake requirement. Thirst is one of the measures of absolute hydration status, other than urinary markers (color, specific gravity, and osmolality) (34).

Table I presents the symptoms of heat stress and their corresponding percentages based on the number of individuals who experienced these symptoms. The most common symptom reported by the respondents is profuse sweating, accounting for 54.62% of the respondents. This is followed by fatigue, severe thirst, rapid breathing, lack of concentration, moist skin, dizziness, and heat rash. These symptoms are reported by more than 29% of the respondents. Meanwhile, headache, dry skin, nausea, fainting, muscle cramps, seizures, confusion, and loss of consciousness are less frequently reported, with each symptom being experienced by less than 30% of the participants.

These symptoms are indicative of the body's response to prolonged exposure to extreme temperatures, and they may vary in severity depending on the individual's age, physical condition, and environmental factors. Heat stress-related symptoms may develop rapidly and lead to heat exhaustion or heat stroke, which can be life-threatening if not promptly addressed. Therefore, it is important to recognize and manage these symptoms to prevent more severe health consequences.

During the interview regarding heat stress-related symptoms score (AHSS), the respondents' answer was scored 0 (0/7) to 1 (7/7) based on 7 main heat stress symptom indicators, i.e., profuse sweating; fatigue; fainting; dizziness; seizures; heat rash and heat stroke. If a respondent answered 1 indicator out of 7, the score was 1/7 or 0.14, while 2 symptoms were present, the score was 2/7 or 0.29, and so forth.

According to Yammamoto et al. (35), they classified heat stress-related symptoms into three categories, i.e., I, II, and III. Stage I refers to any minor heat stress-related symptoms, such as heat cramps, syncope

Table I : Prevalence of heat stress-related symptoms experienced by the workers (%)

Heat stress-related symptoms					
Symptom	**n**	**%**	**Symptom**	**n**	**%**
Heavy sweating	65	54.62	Headache	34	28.57
Fatigue	54	45.38	Dry skin	29	24.37
Severe thirst	46	38.66	Nausea	26	21.85
Rapid breathing	40	33.61	Fainting	19	15.97
Lack of concentration	38	31.93	Muscle cramp	18	15.13
Moist skin	37	31.09	Seizures	18	15.13
Dizziness	36	30.25	Confusion	18	15.13
Heat rash	35	29.41	Loss of consciousness	17	14.29

n = 119

with the signs covering faintness, dizziness, heavy sweating, slight yawning, muscle pain, and muscle cramps. Meanwhile, Stage II is associated with any heat-related illness not included by Stage I or Stage III, such as vomiting, headache, fatigue, a sinking feeling, reduced concentration, and impaired judgment. Finally, Stage III refers to severe conditions of heat stress-related illnesses, such as loss of consciousness, cerebellar signs, or convulsive seizures.

On the other hand, Degham et al. (36) classified heat stress/strain based on the questions scored between -3 to 7, by which each question has its own weighting factor. At the end of the interview session, the score was multiplied by a weighing factor. Based on the score achieved, they classified as safe level when the total score was less than 13.6. The score was between 13.6 to 18. indicated the potential for heat-illnesses and required further evaluation. Meanwhile, a total score, which is greater than 18, indicates that the onsets of heat-induced illnesses very likely and appropriate control measures should be taken as soon as possible to reduce heat strain.

Table II : Index of Acute Heat Symptoms Score (AHSS)

Score	Symptom category	n (%)
1	Very High	0 (0)
0.71 – 0.86	High	5 (4.20)
0.43 – 0.57	Moderate	19 (15.96)
0.14 – 0.29	Low	47 (39.50)
0	No Symptoms	48 (40.34)

Table II shows the distribution of symptom categories based on the Index of Acute Heat Symptoms Score (AHSS), a tool used to assess the severity of heat stress-related symptoms. The majority of respondents (40.34%) scored in the "no symptoms" category with a score of 0, indicating that they did not experience any heat stress-related symptoms. A substantial proportion of respondents (39.50%) scored in the "low" category with a score range of 0.14 – 0.29, suggesting that they had mild heat stress-related symptoms. The "moderate" category, with a score range of 0.43 – 0.57, was reported by 15.96% of respondents, indicating that they had symptoms of moderate severity. Only 4.20% of respondents scored in the "high" category with a score range of 0.71 – 0.86, indicating that they had symptoms of high severity. No respondents scored in the "very high" category with a score of 1, suggesting that none of the respondents experienced severe heat stress-related symptoms that required immediate medical attention.

Overall, the distribution of symptom categories indicates that the majority of respondents did not experience heat stress-related symptoms, and those who did experience symptoms had mild to moderate severity. It is important to note that the AHSS tool is specific to assess heat stress-related symptoms and is not a general tool for assessing other medical conditions. The severity of symptoms can be influenced by several factors such as age, gender, pre-existing medical conditions, and the duration of exposure to heat.

Environmental factors

During the data collection, the weather outside was clear, sunny, without rain. The measurements of WBGT were carried out in three mills with a different number of measurements, namely Steel Mill A 44 times, B 30 times, and C 90 times. The results of WBGT are presented in Table III below. Overall, in the three companies under the study, the average temperature reached 31.99 ^{o}C, while the lowest was at Mill C (28.54 ^{o}C), and the highest was at Mill B (47.92 ^{o}C). The highest humidity level was attributed to Steel Mill C with a mean humidity of 58.03%, followed by Mill A (52.22%) and the lowest was Mill B at 48.90%. Overall, the mean humidity level in the three mills reached 54.10%, Steel Mill B was 30.6% and the highest was found at Steel Mill C, 58.03%.

Table III : WBGT and relative humidity at three steel mills

Mill		WBGT				Relative Humidity			
Mill	**Sample**	**Min**	**Max**	**Ave.**	**Std. dev**	**Min**	**Max**	**Ave.**	**Std. dev**
Steel Mill A	49	29.96	34.58	32.64	1.78	45.00	62.00	52.22	4.38
Steel Mill B	20	31.05	38.52	34.04	1.76	30.60	67.00	48.90	11.18
Steel Mill C	50	28.54	33.98	30.82	1.66	43.80	68.00	58.03	7.61
Total	**119**	**28.54**	**47.92**	**31.99**	**2.47**	**30.60**	**68.00**	**54.10**	**8.04**

WBGT: wet bulb globe temperature

The table (Table III) provides data on the Wet Bulb Globe Temperature (WBGT), relative humidity (RH), and the number of samples taken in three different steel mills (A, B, and C), as well as the total across all mills. The WBGT values range from a minimum of 28.54 to a maximum of 47.92, with an overall average of 31.99 and a standard deviation of 2.47. Steel Mill B has the highest maximum WBGT value of 38.52, while Steel Mill C has the lowest maximum WBGT value of 33.98. The average WBGT value in Steel Mill A (32.64) is the highest among all three mills.

The relative humidity values range from a minimum of 30.60 to a maximum of 68.00, with an overall average of 54.10 and a standard deviation of 8.04. Steel Mill A has the lowest average RH value (52.22), while Steel Mill C has the highest average RH value (58.03). Steel Mill B has the highest RH standard deviation of 11.18, indicating greater variability in RH measurements.

The data suggest that the WBGT values are generally below the recommended threshold limit values for heat stress, which is 32°C in most countries. However, Steel Mill B has a maximum WBGT value that exceeds the threshold limit, which could pose a potential risk to heat stress among workers. It is important for the management of the Steel Mill B to take measures to mitigate the heat stress-related risks by implementing effective heat stress management strategies, such as increasing the frequency and duration of rest breaks, providing workers with adequate hydration and personal protective equipment, and modifying work practices to minimize heat exposure.

The value of the WBGT results in this study was not significantly different from the previous study result in Malaysia conducted by Hazwani et al. (4). The study reported that the average RH of 56.21 % at steel mill workplaces, compared to 58.03 % in this study. Meanwhile, the minimum and maximum WBGTin values in this investigation are 29.96 ^{o}C and 33.98 ^{o}C, respectively, as opposed to 30.01 ^{o}C and 32.67 ^{o}C. It implies that the WBGT result in this study is higher than in the prior study. Furthermore, in another study conducted at steel mills in a subtropical country during the winter, which was cold and dry (9), the WBGT ranged from 25.4 to 33.2 ^{o}C. Because this study is being conducted during the winter in a subtropical climate, the minimum of this value is fair and significantly lower than the value of this study. Furthermore, a prior study of Krishnamurthy et al. (1) discovered that 90% of WBGT measures in their study conducted in Southern India at similar workplaces of steel processing mills were 27.2 – 41.7 ^{o}C, which was considerably higher than that of this study.

Physiological changes

Physiological condition was measured based on changes in three physical indicators, i.e., blood pressure, body core temperature, and heart rate. The workers' physiological conditions of the three companies shown in Table 4 indicates the lowest blood pressure (diastolic) of 104.67 and the highest of 141 with an average of 118.13, while the lowest blood pressure (systolic) was 70.33 and the highest was 89.67 with an average of 79.6. The lowest body temperature was 36.50, the highest was 38.17 with an average of 37.05. The lowest heart rate was 70.67, the highest was 88 with an average of

Table IV : The workers' physiological conditions at three steel mills

Physiological condition & unit	Measurement time	Min	Max	Mean	Stdev
Blood Pressure (Diastolic) (mmHg)	Before Working	105	130	117.20	6.88
	During Working	105	178	120.26	8.47
	After Working	104	131	116.93	6.71
Blood Pressure (Systolic) (mmHg)	Before Working	70	90	79.64	5.99
	During Working	70	90	80.61	5.42
	After Working	70	90	78.55	5.65
Body Core Temperature (^{o}C)	Before Working	36.50	37.92	37.02	1.14
	During Working	36.72	38.17	37.68	1.25
	After Working	36.61	38.04	37.21	1.30
Heart rate (beats per minute, bpm)	Before Working	70	90	80.19	5.45
	During Working	58	91	80.29	6.27
	After Working	70	96	78.76	5.59

79.75. Based on the above results, i.e., the maximum body core temperature of the worker is 38,17°C, the highest temperature of the operator is still below the limit value (38.5 °C), which is still considered safe, according to the standard released by WHO (1969), ACGIH (1989) (37).

Table IV presents the physiological condition of workers in a particular working environment. The measurements were taken before, during, and after work. For blood pressure, both diastolic and systolic measurements were taken. Before working, the diastolic pressure ranged from 105 to 130 mmHg with a mean of 117 mmHg and standard deviation of 6.88. During working, the diastolic pressure ranged from 105 to 178 mmHg, which was the highest value compared all, with a mean of 120 mmHg and standard deviation of 8.47. After working, the diastolic pressure ranged from 104 to 131 mmHg with a mean of 117 mmHg and standard deviation of 6.71. Before working, the systolic pressure ranged from 70 to 90 mmHg with a mean of 80 mmHg and standard deviation of 5.99. During working, the systolic pressure ranged from 70 to 90 mmHg with a mean of 81 mmHg and standard deviation of 5.42. After working, the systolic pressure ranged from 70 to 90 mmHg with a mean of 79 mmHg and standard deviation of 5.65.

For body core temperature, the measurements were also taken before, during, and after working hours. Before working, the body core temperature ranged from 36.50 to 37.92 °C with a mean of 37.02 °C and standard deviation of 1.14. During working, the body core temperature ranged from 36.72 to 38.17 °C with a mean of 37.68 °C, which was the highest among all, and standard deviation of 1.25. After working, the body core temperature ranged from 36.61 to 38.04 °C with a mean of 37.21 °C and standard deviation of 1.31.

For the heart rate, the measurements were also taken before, during, and after working hours. Before working, the heart rate ranged from 70 to 90 beats per minute (bpm) with a mean of 80 bpm and standard deviation of 5.45. During working, the heart rate ranged from 58 to 91 bpm with a mean of 80 bpm and standard deviation of 6.27. After working, the heart rate ranged from 70 to 96 bpm with a mean of 79 bpm and standard deviation of 5.59.

The measurement results suggest that the workers experience a rise in blood pressure, body core temperature, and heart rate during working hours, which return to the baseline after work. The standard deviations suggest some variability in these measurements among the workers. It's important to note that the measurements were taken in a specific working environment, and the interpretation of the results should be made with caution and in the context of the specific workplace conditions.

To assess the heart-stress related symptoms predictive model, the stepwise regression analysis was conducted by regressing WBGT, body core temperature and heart rate. The result of stepwise regression analysis is shown in Table V.

The result of multiple regression analysis shows that, at a significance level of 0.05, the three variables, namely WBGT, body core temperature, and heart rate, had a significant effect on heat stress-related symptoms. The other three variables, RH, systolic blood pressure, and diastolic blood pressure, have no significant effect. The F count value is 58.22

Table V : Heat stress-related symptoms predictive model

Variables	Beta	SE	F	p	Adj. R^2	p
(Constant)	-11.48	4.79	12.26	0.001	0.09	0.018
WBGT	0.52	0.15				0.001
(Constant)	-46.47	10.22	14.13	0.001	0.18	0.001
WBGT	0.43	0.14				0.004
Body Temperature)	1.06	0.28				0.001
(Constant)	-77.07	7.75	58.22	0.001	0.59	0.001
WBGT	0.36	0.10				0.001
Body Temperature)	0.92	0.20				0.001
Heart Rate	0.47	0.04				0.001

*p < 0.05

with a p-value of 0.00 (<0.05), indicating that all the independent variables had a significant effect on heat stress-related symptoms at the same time. The R^2 in the model is 0.59, indicating that these three independent variables influence 59.3 % of changes in employees' heat stress-related symptoms, whereas the remaining 40.3 % is influenced by additional factors not examined in this research.

Table V shows the stepwise regression analyses. The results suggest that WBGT, body temperature, and heart rate are all positively associated with heat stress symptoms. WBGT, body temperature, and heart rate are all independent variables. The constant term is -77.07, and WBGT has a coefficient of 0.36 and a statistically significant t-value of 3.55 (p=0.001). Body temperature has a coefficient of 0.92 and a statistically significant t-value of 4.68 (p=0.001). Heart rate has a coefficient of 0.47 and a statistically significant t-value of 10.86 (p=0.001). The adjusted R-squared for this model is 0.59, which means that the independent variables explain 59% of the variation in heat stress symptoms.

DISCUSSION

Predictive index of heat stress-related symptoms

Out of the total 119 respondents, severe thirst and excessive sweating are the heat stress related symptoms most of the workers experienced due to hot environment. Excessive sweating is body response as thermoregulation to maintain body temperature at normal range. In addition, there was a significant and positive correlation among the factors, of sweat rate, sweat volume, and perception of thirst, and sodium concentration (39). As well recognized, sodium ion is one of the elemental constituents in human sweat. Thus, dehydration will decrease the content of sodium ions in the body. In a warm environment, excessive sweating, as indicated by excessive liquid excretion and dehydration are typical of heat exhaustion (40).

The multiple regression test was used to examine the factors that predict heat stress-related symptoms. A model test (classical assumption test) was performed in this study, which included the normality, linearity, autocorrelation, multicollinearity, and heteroscedasticity tests.

Multiple regressions of predictive model

Multiple regression analysis was used to test the presence or absence of the influence of the independent variable on the dependent variable used in the analysis model. There are six predictor variables (independent) included in the test model, i.e., WBGT, relative humidity, blood pressure systolic, blood pressure diastolic, body core temperature, and heart rate. The effect of the independent variable on the dependent variable was indicated by the regression coefficient. The results of multiple regression testing for Model 1 can be described as follows: R = 0.75, R square 0.57, adjusted R square = 0.55, std. error of the estimate = 2.02, R square change = 0.57, F change = 24.67, sig. F change 0.000, and Durbin-Watson = 1.69. For Predictors, in R-value, consists of (constant), heart rate, diastolic, WBGT, systolic, body temperature), and humidity, the dependent variable is heat stress-related symptoms.

Correlation coefficient of predictive model

The R-value shows the relationship between the dependent variable and the observed independent variable (correlation). Based on the results of the analysis, R-value was 0.784 or 78.4%, meaning that the variables WBGT, relative humidity, blood pressure systolic, blood pressure diastolic, body core temperature and heart rate simultaneously have a strong correlation with heat stress-related symptoms.

Predictive index of heat stress-related symptoms

The results of data processing in Table V show at a significance level of 0.05 (5%), the three variables, i.e., WBGT, body core temperature, and heart rate, have a significant effect on heat stress-related symptoms. The other three variables, namely RH, blood pressure systolic and blood pressure diastolic, have no significant effect. The predictive index of heat stress-related symptoms of workers are as follows:

Heat stress-related symptoms = (-77.07) + (0.36 x WBGT) + (0.92 x body core temperature) + (0.47 x heat rate)

The conclusions from these results are as follows:

1. An increase in WBGT by 1 unit while the heart rate and body core temperature are constant (0) will increase heat-stress related symptoms by 0.36.
2. An increase in body core temperature by 1 unit while heart rate and WBGT are constant (0), will increase heat stress-related symptoms by 0.92.
3. An increase in heart rate by 1 unit while body core temperature and WBGT are constant (0), will increase heat stress-related symptoms by 0.47.

In comparison, Aggarwal et al. (41) developed a predictive model to detect human cutaneous vascular response/changes with other physiological parameters; thus, heat stress-related illnesses, such as heat edema, heat cramp, heat syncope, heat exhaustion, and heat stroke can be estimated. In their study, temperature changes (°C) and exposure time. Using this predictive model, one can early prevent heat-related illnesses with a proper protection. This accurate prediction is attributed to the integration of changes in forearm blood flow with the rise of skin temperature, and changes of environmental factors.

Furthermore, a study that developed a predicted model was also conducted by Du et al. (42). However, they predicted human physiological responses ranging from rectal temperature, skin temperature, sweat rate, and heart rate in response to varied room temperatures and relative humidity. The protection was improved to 71.2% when Predicted Heat Stress was adjusted with the maximum heart rate based on age, and it improved to 68.2% when the real-time heart rate to predict metabolic rates was adopted.

CONCLUSION

Workers laboring at steel mills workplaces, particularly in the tropical region are susceptible to heat stress. The study results revealed that based on WBGT value, working pattern, and clothing factors, workers working at three steel mills located in East Java Province, Indonesia experienced heat stress, indicated by physiological responses due to heat stress. Based on data analysis, there was a strong correlation between the dependent variable and the observed independent variable (correlation), i.e., WBGT, body core temperature and heart rate with heat stress-related symptoms, while humidity, blood pressure systolic and diastolic have insignificant correlation with heat stress-related symptoms.

Based on the predictive model of correlation between dependent and independent variables, an increase in WBGT by 1 unit while the heart rate and body core temperature are constant (0) will increase heat stress-related symptoms by 0.36. Furthermore, when body core temperature increases by 1 unit, while heart rate and WBGT are constant (0), it will increase heat stress- related symptoms by 0.92. Finally, when heart rate increases by 1 unit while body core temperature and WBGT are constant (0), heat stress-related symptoms will also increase by 0.47. Among all indicators of independent variables, i.e., WBGT, body core temperature, and heart rate, body core temperature has the highest value of constant, indicating that it has the most significant variable that influences heat stress-related symptoms.

The limitation of the study is that the authors did not measure the sweat rate of the respondents during the data collection to be incorporated into the model due to instrument unavailability during travel restriction of Covid-19 pandemic. Future study is expected to include sweating rate as one of the indicators of heat-related symptoms prediction model.

ACKNOWLEDGMENT

We would like to gratefully acknowledge to PT Bhirawa Steel, PT Jatim Taman Steel, PT Ispatindo, and UPT K3 Jatim providing the opportunity to the authors in conducting data collection.

REFERENCES

1. Krishnamurthy M, Ramalingam P, Perumal K, Kamalakannan LP, Chinnadurai J, Shanmugam R, et al. Occupational Heat Stress Impacts on Health and Productivity in a Steel Industry in Southern India. Saf Health Work [Internet]. 2017;8(1):99–104. Available from: http://dx.doi.org/10.1016/j.shaw.2016.08.005
2. Zhang Y, Held I, Fueglistaler S. Projections of tropical heat stress constrained by atmospheric dynamics. Nat Geosci. 2021;14(3):133–7.
3. Sobolewski A, Młynarczyk M, Konarska M, Bugajska J. The influence of air humidity on human heat stress in a hot environment. Int J Occup Saf Ergon [Internet]. 2021;27(1):226–36. Available from: https://doi.org/10.1080/10803548.2019.1699728
4. Suadi Nata DHM, Tamrin SBM. Assessment on physiological effects of heat stress among palm oil mill in tropical climate condition. Adv Environ Biol. 2014;8(15):67–71.
5. Flouris AD, Dinas PC, Ioannou LG, Nybo L, Havenith G, Kenny GP, et al. Workers' health and productivity under occupational heat strain: a systematic review and meta-analysis. Lancet Planet Heal [Internet]. 2018;2(12):e521–31. Available from: http://dx.doi.org/10.1016/S2542-5196(18)30237-7
6. Yon H, Che Amat H, Abdul Manap MF, Hasan R, Yeop Z, Mat Akat M, et al. Department of Occupational Safety and Health Heat Stress. 2016;52. Available from: https://www.dosh.gov.my/index.php/legislation/guidelines/industrial-hygiene-1/2017-guidelines-heat-stress-management-at-workplace/file
7. Rasdan Ismail A, Jusoh N, Amin Mahd Asri M, Md Zein R, Abdul Rahman I, Kamilah Makhtar N, et al. The factor affecting heat stress in industrial workers exposed to extreme heat: A case study of methodology. J Phys Conf Ser. 2020;1630(1).
8. Hodder SG, Parsons K. The effects of solar radiation on thermal comfort. Int J Biometeorol. 2007;51(3):233–50.
9. Chen ML, Chen CJ, Yeh WY, Huang JW, Mao IF. Heat stress evaluation and worker fatigue in a steel plant. Am Ind Hyg Assoc J. 2003;64(3):352–9.
10. Fahed A karim, Ozkaymak M, Ahmed S. Impacts of heat exposure on workers' health and performance at steel plant in Turkey. Eng Sci Technol an Int J [Internet]. 2018;21(4):745–52. Available from: https://doi.org/10.1016/j.jestch.2018.05.005
11. Venugopal V, Latha PK, Shanmugam R, Krishnamoorthy M, Johnson P. Occupational heat stress induced health impacts: A cross-sectional study from South Indian working population. Adv Clim Chang Res [Internet]. 2020;11(1):31–9. Available from: https://doi.org/10.1016/j.accre.2020.05.009

12. Boonruksa P, Maturachon T, Kongtip P, Woskie S. Heat stress, physiological response, and heat related symptoms among Thai sugarcane workers. Int J Environ Res Public Health. 2020;17(17):1–15.
13. Zheng G, Li K, Wang Y. The effects of high-temperature weather on human sleep quality and appetite. Int J Environ Res Public Health. 2019;16(2):1–13.
14. OHSA. OSHA technical manual. Washington D.C.: U.S. Dept. of Labor, Occupational Safety and Health Administration; 1999.
15. Yamamoto T, Todani M, Oda Y, Kaneko T, Kaneda K, Fujita M, et al. Predictive factors for hospitalization of patients with heat illness in Yamaguchi, Japan. Int J Environ Res Public Health. 2015;12(9):11770–80.
16. Nerbass FB, Pecoits-Filho R, Clark WF, Sontrop JM, McIntyre CW, Moist L. Occupational Heat Stress and Kidney Health: From Farms to Factories. Kidney Int Reports [Internet]. 2017;2(6):998–1008. Available from: https://doi.org/10.1016/j.ekir.2017.08.012
17. Junglee NA, di Felice U, Dolci A, Fortes MB, Jibani MM, Lemmey AB, et al. Exercising in a hot environment with muscle damage: Effects on acute kidney injury biomarkers and kidney function. Am J Physiol - Ren Physiol. 2013;305(6):813–21.
18. Chan APC, Yam MCH, Chung JWY, Yi W. Developing a heat stress model for construction workers. J Facil Manag. 2012;10(1):59–74.
19. Lazaro P, Momayez M. Development of a modified predicted heat strain model for hot work environments. Int J Min Sci Technol [Internet]. 2020;30(4):477–81. Available from: https://doi.org/10.1016/j.ijmst.2020.05.009
20. Seo Y, Powell J, Straucha A, Robergea R, Kenny GP, Kim J-H. Heat stress assessment during intermittent work under different environmental conditions and clothing combinations of effective wet bulb globe temperature (WBGT). J Occup Environ Hyg. 2019;16(7):467–76.
21. Zamanian Z, Sedaghat Z, Hemehrezaee M, Khajehnasiri F. Evaluation of environmental heat stress on physiological parameters. J Environ Heal Sci Eng. 2017;15(1):1–8.
22. Hajizadeh R, Golbabaei F, Jafari SFDMHBSM, Taheri F, Golbabaei RHF, Beheshti SFDMH, et al. Validating the heat stress indices for using in heavy work activities in hot and dry climates. J Res Health Sci. 2016;16(2):90–5.
23. Błazejczyk K, Jendritzky G, Brude P, Fiala D, Havenith G, Epstein Y, et al. An introduction to the Universal thermal climate index (UTCI). Geogr Pol. 2013;86(1):5–10.
24. Zare S, Hasheminejad N, Shirvan HE, Hemmatjo R, Sarebanzadeh K, Ahmadi S. Comparing Universal Thermal Climate Index (UTCI) with selected thermal indices/environmental parameters during 12 months of the year. Weather Clim Extrem [Internet]. 2018;19(January):49–57. Available from: https://doi.org/10.1016/j.wace.2018.01.004
25. Vatani J, Golbabaei F, Dehghan SF, Yousefi A. Applicability of universal thermal climate index (UTCI) in occupational heat stress assessment: A case study in brick industries. Ind Health. 2016;54(1):14–9.
26. Ioannou LG, Tsoutsoubi L, Mantzios K, Flouris AD. A free software to predict heat strain according to the ISO 7933:2018. Ind Health. 2019;57(6):711–20.
27. Yousif TA, Tahir HMM. Application of Thom's Thermal Discomfort Index in Khartoum State, Sudan. J For Prod Ind. 2013;2(5):36–8.
28. Kjellstrom T, Holmer I, Lemke B. Workplace heat stress, health and productivity-an increasing challenge for low and middle-income countries during climate change. Glob Health Action. 2009;2(1):46–52.
29. Kwon J, Parsons K. Evaluation of the Wet Bulb Globe Temperature (WBGT) Index for Digital Fashion Application in Outdoor Environments. J Ergon Soc Korea. 2017;36(1):23–36.
30. Weir CB JA. BMI Classification Percentile And Cut Off Points. StatPearls [Internet] [Internet]. 2023;(Updated 2022 Jun 27). Available from: https://www.ncbi.nlm.nih.gov/books/NBK541070/
31. ACGIH. Threshold limit values for chemical substances and physical agents and biological exposure indices. ACGIH Worldwide, Signature Publications. 2004. 109–128 p.
32. ACGIH TLVs and BEIs. Upper Limb Localized Fatigue TLV. Threshold Limit Values and Biological Exposure Indices. 2019. 209–211 p.
33. ACSM. Prevention of thermal injuries during distance running. Med Sci Sport Exer. 1984;16(5):427–43.
34. McCubbin AJ, Allanson BA, Caldwell Odgers JN, Cort MM, Costa RJS, Cox GR, et al. Sports Dietitians Australia position statement: Nutrition for exercise in hot environments. Int J Sport Nutr Exerc Metab. 2020;30(1):83–98.
35. Yamamoto T, Fujita M, Oda Y, Todani M, Hifumi T, Kondo Y, et al. Evaluation of a novel classification of heat-related illnesses: A multicentre observational study (heat stroke STUDY 2012). Int J Environ Res Public Health. 2018;15(9).
36. Dehghan H, Mortzavi SB, Jafari MJ, Maracy MR. Development and validation of a questionnaire for preliminary assessment of heat stress at workplace. J Res Health Sci. 2015;15(3):175–81.
37. McNeill MB, Parsons KC. Appropriateness of international heat stress standards for use in tropical agricultural environments. Ergonomics. 1999;42(6):779–97.
38. Viljoen SA, Reinecke AJ. Physiologic Responses and Long-Term Adaptations to Exercise. In: Physical Activity and Health. 1996. p. 225–36.
39. Amabebe E, Omorodion S, Ozoene J, Ugwu

A, Obika L. Sweating and thirst perception in premenopausal, perimenopausal and postmenopausal women during moderate exercise. J Exp Integr Med. 2013;3(4):279.
40. Leyk D. Health Risks and Interventions in Exertional Heat Stress. Dtsch Arztebl Int. 2019;(Mc).
41. Aggarwal Y, Karan BM, Das BN, Sinha RK. Prediction of heat-illness symptoms with the prediction of human vascular response in hot environment under resting condition. J Med Syst. 2008;32(2):167–76.
42. Du C, Li B, Li Y, Xu M, Yao R. Modification of the Predicted Heat Strain (PHS) model in predicting human thermal responses for Chinese workers in hot environments. Build Environ [Internet]. 2019;165(May):106349. Available from: https://doi.org/10.1016/j.buildenv.2019.106349